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UNITED STATES PATENT APPLICATION

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for

**PISTON ASSEMBLY FOR ROTARY HYDRAULIC MACHINES**

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# **PISTON ASSEMBLY FOR ROTARY HYDRAULIC MACHINES**

## **BACKGROUND OF THE INVENTION**

### **FIELD OF THE INVENTION**

**[0001]** The present invention relates to hydraulic machines.

### **DESCRIPTION OF THE PRIOR ART**

**[0002]** There are many different types of hydraulic machines that can be used to convert mechanical energy into fluid energy and vice versa. Such machines may be used as a pump in which mechanical energy is converted into a flow of fluid or as a motor in which the energy contained in a flow of fluid is converted into mechanical energy. Some of the more sophisticated hydraulic machines are variable capacity machines, particularly those that utilize an inclined plate to convert rotation into an axial displacement of pistons or vice versa.

**[0003]** Such machines are commonly referred to as swashplate pumps or motors and have the attribute that they can handle fluid under relatively high pressure and over significant range of flows. A particular advantage of such machines is the ability to adjust the capacity of the machine to compensate for different conditions imposed upon it.

**[0004]** The swashplate machines are, however, relatively complex mechanically with rotating and reciprocating components that must be manufactured to withstand large hydraulic and mechanical forces. These constraints lead to a reduction in the efficiency due to mechanical and hydraulic losses, a reduced control resolution due to the mechanical inefficiencies and the required size and mass of the components and a relatively expensive machine due to the manufacturing complexity.

**[0005]** In use as a variable capacity machine the swashplate is modulated to achieve a desired movement of component of a machine, either a position, rate of movement or applied force.

**[0006]** The movement of the swashplate is usually controlled by a valve supplying fluid to an actuator that acts through a compression spring on the swashplate. Control signals for the valve

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are generated from a set controller and a feedback, typically provided by a sensed parameter. In its simplest form the feedback may be provided by the operator who simply opens and closes the valve to achieve the desired movement or positioning of the component. More sophisticated controls however sense preselected parameters and provide feedback signals to a valve controller. The valve controller may be mechanical, hydraulic but more usually electronic to offer greater versatility in the control functions to be performed.

[0007] Typically the ball joint is formed on the piston and a socket is formed on the slipper to receive the ball joint. The loads imposed on the pistons as pressure is generated in the cylinders is transferred through the ball joint and therefore such a joint must be sufficiently robust to take the maximum loads at the maximum displacement of the swashplate. In practice, the eccentric loading imposed on the ball joint has limited the angular displacement of the swashplate and moreover made the ball joint expensive to manufacture.

[0008] It is therefore an object to the present invention to obviate or mitigate the above disadvantages.

#### SUMMARY OF THE INVENTION

[0009] In accordance to one aspect to the present invention, there is provided a hydraulic machine comprising a housing, and a rotating group rotatably mounted within the housing. The rotating group includes a barrel and a plurality of pistons axially slideable in cylinders in the barrel. A swashplate assembly engages the pistons and induces reciprocation thereof as the barrel rotates in the housing. A port plate is interposed between the barrel and the housing and is effective to connect respective ones of the cylinders alternatively with an inlet port and an outlet port. A slipper assembly acts between the swashplate and the piston to transfer loads therebetween. The slipper assembly includes a base having a planar bearing surface engagable with the swashplate and a spherical bearing engagable with a part spherical recess in the piston.

[0010] In accordance with a further aspect of the invention there is provided a slipper assembly for a piston assembly of a rotary hydraulic machine, the slipper assembly comprising a base having a planar bearing surface disposed on one side for engagement with a swashplate and a spherical bearing disposed on an oppositely directed side for engagement with a part spherical recess in the piston. ...

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[0011] According to a still further aspect of the invention there is provided a piston assembly for a rotating hydraulic machine comprising a piston having a spherical recess at one end thereof and a slipper assembly including a base having planar bearing surface on one side and a spherical bearing on an oppositely directed side thereof. The spherical bearing is located within the spherical recess to provide limited pivotal movement between the piston and slipper assembly.

[0012] According to a yet further aspect of the present invention there is provided a method of forming a piston assembly for a rotary hydraulic machine comprising the steps of forming a part spherical cavity in one end of a piston to an axial depth greater than the diameter of said cavity, inserting therein a complementary spherical bearing of a slipper assembly, and deforming the walls of the cavity to conform to the surface of the spherical bearing.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Embodiments of the invention will now be described by way of example only with reference to the accompanying drawings in which:

[0014] Figure 1 is a side elevation of a hydraulic machine.

[0015] Figure 2 is a top view of the hydraulic machine of Figure 1.

[0016] Figure 3 is a view on the line III-III of Figure 2.

[0017] Figure 4 is a view on the line IV-IV of Figure 1.

[0018] Figure 5 is a perspective view of the rotating components of the machine shown in Figures 3 and 4.

[0019] Figure 6 is an exploded perspective view of the component shown in Figure 5.

[0020] Figure 7 is a front perspective view, partly in section of the assembly shown in Figure 3.

[0021] Figure 8 is a perspective view of a portion of the machine in the direction of arrow VIII-VIII of Figure 3.

[0022] Figure 9 is an enlarged view of the portion of the machine shown in Figure 4 within the circle A.

[0023] Figure 10 is a schematic representation of the assembly of a set of components used in the machine of Figures 4 and 5.

[0024] Figure 11 is a view on the line XI-XI of Figure 1.

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- [0025] Figure 12 is a top view on the line XII-XII of Figure 1.
- [0026] Figure 13 is a view similar to Figure 12 showing alternate positions of the components of the machine shown in Figures 4 and 5.
- [0027] Figure 14 is a view on the line XIV-XIV of Figure 1.
- [0028] Figure 15 is a section on line XV-XV of Figure 3.
- [0029] Figure 16 is a view on the line XVI-XVI of Figure 15.
- [0030] Figure 17 is a schematic hydraulic circuit showing the operation of the components shown in figure 1 to 16.
- [0031] Figure 18 is a section through a tool used to assemble the components shown schematically in Figure 10.
- [0032] Figure 19 is a detailed view of a portion of the tool shown in Figure 18.
- [0033] Figure 20 is a plain view of a further tool used to assemble the components shown in Figure 10.
- [0034] Figure 21 is a view similar to Figure 4 of an alternative embodiment of machine.
- [0035] Figure 22 is a front view of a port plate used in the embodiment of Figure 4.
- [0036] Figure 23 is a side view of the port plate of Figure 22.
- [0037] Figure 24 is a rear view of the port plate of Figure 23.
- [0038] Figure 25 is a section on the line XXV – XXV of Figure 22.
- [0039] Figure 26 illustrates the sequential movement of a cylinder across a port plate of Figure 22

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0040] Referring therefore to Figures 1 through 4, a hydraulic machine 10 includes a housing 12 formed from a casing 14, an end plate 16 and a control housing 18. The casing 14 has an opening 15 on its upper side with a planar sealing surface 17 around the opening 15. The control housing 18 has a lower surface 19 that extends across the opening 15 and is secured to the casing 14. The control housing 18, end plates 16 and casing 14 define an internal cavity 20 in which the rotating group 22 of the machine 10 is located.

[0041] As can be seen in Figures 3, 4, 5 and 6, the rotating group 22 includes a drive shaft 24 that is rotatably supported in the casing 14 on a roller bearing assembly 26 and sealed with a seal

assembly 28. One end of the drive shaft 24 projects from the casing and includes a drive coupling in the form of a key 30 for connection to a drive or driven component (not shown) e.g. an engine, electric motor or wheel assembly. The opposite end 32 of the drive shaft 24 is supported in a roller bearing 34 located in a bore 36 of the end plate 16. The shaft 24 is thus free to rotate along a longitudinal axis A-A of the housing 12.

[0042] A barrel 40 is secured to the shaft 24 by a key 42 located in a key way 44 formed in the shaft 24. The barrel 40 similarly has a key way 46 that allows the barrel 40 to slide axially onto the shaft 24 and abut against a shoulder 48 formed on a drive shaft 24. The barrel 40 is provided with a set of axial bores 50 uniformly spaced about the axis of the shaft 24 and extending between oppositely directed end faces 52,54. As can be seen in greater detail in Figure 9, each of the bores 50 is lined with a bronze sleeve 56 to provide a sliding bearing for a piston assembly 58, described in greater detail below.

[0043] A toothed ring 60 is secured on the outer surface of the barrel 40 adjacent the end face 52. The toothed ring 60 has a set of uniformly spaced teeth 62 each with a square section and is a shrink fit on the barrel 40. The barrel 40 is formed from aluminium and the toothed ring 60 from a magnetic material.

[0044] A port plate 64 is located adjacent to the end face 54 and has a series of ports 66 at locations corresponding to the bores 50 in the barrel 40. The port plate 64 is located between the barrel 40 and the end plate 16 and is biased into engagement with the end plate 16 by coil springs 68 and a conical washer 70. The coil springs 68 are positioned at the radially outer portion of the barrel 40 and between adjacent bores 50 to bias the radially outer portion of the plate 64 into engagement with the end plate 16. As seen more clearly in Figure 9, the conical washer 70 is located at the radially inner portion of the barrel 40 and its radially outer edge received in a recess 72 formed in the port plate 64 to urge the inner portion against the end plate 16. The port plate 64 is thus free to float axially relative to the barrel 40.

[0045] To provide fluid transfer between the bores 50 and the ports 66, an annular sleeve 74 is located within each of the bores 50 and sealed by an O-ring 76. The opposite end of the sleeve 74 is received in the circular recess 67 of the port 66, as best seen in Figure 9, and is located axially by a shoulder 68 provided on the sleeve 74. A fluid tight seal is thus provided between

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the barrel 40 and the port plate 64. The ports 66 smoothly transform from a circular cross-section facing the bore 50 to an arcuate slot for co-operation with conduits 78, 79 formed in the end plate 16.

[0046] As most readily seen in Figure 8, the end plate 16 has a pair of kidney ports 80, 82 disposed about the bore 36. The kidney ports 80, 82 connect pressure and suction conduits 78, 79 respectively to fluid entering and leaving the bores 50. The end plate 16 has a circular bearing face 84 that is upstanding from the end plate 16 and has a set of radial grooves 86 formed in a concentric band about the axis of the shaft 24. The grooves 86 provide a hydrodynamic bearing between the port plate 64 and the bearing face 84 in order to maintain a seal whilst facilitating relative rotation between the port plate 64 and face 84.

[0047] Referring again to Figure 4 and 9, each of the piston assemblies 58 is axially slideable within a respective sleeve 56 and comprises a tubular piston 90 and a slipper 92 interconnected by a ball joint 94. The piston 90 is formed from a tube that is heat treated and ground to diameter to be a smooth sliding fit within the sleeves 56. As can be seen in greater detail in Figure 10, the outer surface of one end 96 of the piston 90 is reduced as indicated at 98 and a part spherical cavity 100 formed on the inner walls of the end 96. The cavity 100 is dimensioned to receive a ball 102 with a through bore 104. The cavity 100 has an axial depth greater than the radius of the ball 102 so that the inner walls extend beyond the equator of the ball 102. The bore 104 in ball 102 is stepped as indicated at 106 to provide an increased diameter at its inner end.

[0048] During the first step of forming of the piston assembly 58, indicated at 109, the ball 102 is inserted in the cavity 100 with the bore 104 aligned generally with the axis of the piston 90. To retain the ball 102 in the cavity 100, the reduced section 98 of the piston 90 at the end 96 is swaged about the ball 100 indicated in Figure 10 (b).

[0049] Slipper 92 that has a stem 110 and a base 112 is inserted into the bore 104 (step (c)). A passageway 114 is formed through the stem 110 to communicate between the interior of the piston 90 and a recess 116 formed in the base 112. The slipper 92 is secured to the ball 102 by swaging, the end of the stem 110 so it is secured by the step 106, as shown in step (d).

[0050] After securing the slipper to the ball, a radial force is applied to the equator of the ball as indicated by the arrows F in Figure 10e that has the effect of displacing the material on the



equator to provide a small clearance between the ball 102 and cavity 100. This clearance enables the ball joint 94 to rotate smoothly within the cavity 100 whilst maintaining an effective seal from the interior of the piston.

[0051] The process shown in Figure 10 may conveniently be performed using the tool set shown in Figures 18, 19 and 20. A tool set 120 has a fixed die 122 and a moveable die 124. The fixed die 122 is secured to a base plate 126 and has a central pin 128 on which the piston 90 is located. A supporting sleeve 130 supports the upper end of the piston 90 adjacent to the reduction 98. The pin 128 also aligns the ball 102 by extending into the bore 104 of the ball 102.

[0052] The moveable die 124 is formed with a part spherical recess 132 dimensioned to engage the end 96 and form it about the ball 102. The moveable die may be advanced into engagement with the ball 102 through the action of a press in which the tool set 120 is mounted.

[0053] After forming, the piston assembly 58 is inserted into a 3 disk die 134 shown in Figure 20. The 3 disk die has a pair of driven rollers 135 and an idler roller 136 that are disposed around the circumference of the end 96 of the piston assembly 58 to form point contact with the outer surface 98. The idler roller 136 is moveable along a radial path by means of a hydraulic cylinder 137 that applies a constant force to the roller 136. The advance of the roller is controlled by a flow control valve 138 until the material surrounding the equator of the ball 102 is sufficiently displaced to provide free movement of the ball within the cavity.

[0054] Referring again to Figures 4, 5 and 6 of the base 112 of the slipper 92 engages a swashplate assembly 140 supported within the housing 14. The swashplate assembly 140 includes a semi cylindrical swashplate 142 having a generally planar front face 144 and an arcuate rear face 146. The planar front face 144 has a recess 148 to receive a lapped plate 150 against which the slippers 92 bear. The slippers 92 are held against the plate 150 by a retainer 152 that has holes 154 through which the piston assemblies 58 project. The holes 154 are dimensioned to engage the outer periphery of the base 112 of the slipper 92 and inhibit axial movement relative to the plate 150. The retainer 152 is located axially by a pair of C-shaped clamps 156 that are secured to the front face 144 of the swashplate 142. The base 112 thus bears against the lapped face of the plate 150 as the barrel is rotated by the drive shaft 24.

[0055] The rear face 146 of the swashplate 142 is supported on a complimentary curved surface 158 of the casing 14 opposite the end plate 16. The rear face 146 is coated with a polymer to reduce friction between the face 146 and surface 158. A suitable polymer coating is a nylon coating formulated from type 11 polyamide resins, such as that available from Rohm & Haas under the trade name CORVEL. A 70 000 series has been found suitable although other grades may be utilized depending on operating circumstances. After deposition on the face 146, the coating is ground to a uniform thickness of approximately 0.040 inches.

[0056] As seen in Figure 7, a pair of grooves 160, 162 respectively are formed in the rear face 146 and terminate prior to the linear edges of the face 146 to provide a pair of closed cavities. The grooves 160, 162 are generally aligned with the kidney ports 80, 82 formed in the end plate 16 and it will be noted that the width of the groove 160 which is aligned with the pressure conduit is greater than the width of the groove 162 aligned with the suction conduit. Fluid is supplied to the grooves 160, 162 through internal passageways 164, 166 respectively formed in the casing 14. Flow through the passageways is controlled by a pair of pressure compensated flow control valves 168 that supply a constant flow of fluid to the grooves 160, 162. The grooves 160, 162 thus provide a fluid bearing for the rear face 146 against the surface 158 to facilitate rotational movement of the swashplate 142.

[0057] Adjustment of the swashplate 142 about its axis of rotation is controlled by a pair of actuators 170, 172 respectively located in the casing 14. As shown most clearly in Figures 5 and 11, each of the actuators 170, 172 includes a cylinder 174 in which a piston 176 slides. Each of the cylinders 174 is received within a bore 178 formed in the casing 14 and extending from the end plate 16 into the cavity 20. The cylinders 174 have an external thread 180 which engages with an internal thread on the bore 178 to secure the cylinder in the casing 14. The end plate 16 (Figure 8) has a pair of recesses 192 that fit over the end of the pistons 176. The self contained actuator, 170, 172 located in the casing 14 ensures that axial load generated by the actuators 170 are imposed on the casing 14 rather than across the joint between the end plate 16 and casing 14 to maintain integrity of the housing 12.

[0058] The cylinder 174 is provided with cross drillings 182 to permit fluid supplied through internal passageways 183 (Fig. 12) in the housing 14 to flow to and from the interior of the

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cylinder 174. A spring 184 acts between the cylinder 174 and piston 176 to bias it outwardly into engagement with the swashplate assembly 140. Preferably one of the springs 184 has a greater axial force than the other so that the swashplate is biased to a maximum strike position in the absence of fluid in the actuators 170, 172.

[0059] The actuators 170, 172 bear against a horseshoe extension 186 of the swashplate 142 that projects outwardly above the barrel 40. The extension 186 has a pair of part cylindrical cavities 188 at opposite ends into which a cylindrical pin 190 is located. The cavities 188 are positioned such that the outer surface of the pin 190 is tangential to a line passing through the axis of rotation of the swashplate. The end face of piston 176 engages the outer surface of the pin 190 to control the position of the swashplate.

[0060] As illustrated in Figure 13, extension of the piston 176 of one of the actuators 170, 172 will induce rotation of the swashplate assembly 140 in the casing 14 and cause a corresponding retraction of the other of the actuators 170, 172. The assembly 140 slides over the curved surface 158 and as the assembly 140 rotates, the pins 190 maintain contact with the end face of the pistons 170. The position of the pins 190 on a common diameter of the swashplate assembly ensures that a rolling motion, rather than sliding, is provided across the end face of the pistons 176 to reduce friction during the adjustment. As can be seen in Figure 13, the actuators 170, 172 are disposed to provide a full range of rotation on both sides of a neutral or no stroke position with rolling contact being made over this range of motion.

[0061] Flow to the actuators 170, 172 is controlled by a control valve 200, Figure 14, located in the control housing 18. The control valve 200 is a solenoid operated, spool valve having a centred position in which no flow is permitted through the valve. The spool may be moved to either side of the centred position to apply pressure to one of the actuators and connect the other actuator to drain. The control housing 18 is shown in greater detail in Figures 3, 15 and 16 has a peripheral skirt 191 extending from a base 192. A pair of bores 193, 194 extend through the base 192 to receive control valve 200 and an accumulator 220 respectively. Fluid is supplied to the bores 193, 194 by an internal supply gallery 195 and a drain gallery 196 is connected between the bore 193 and the cavity 20 of the casing 12. Internal galleries 197, 198 also communicate between the bore 193 and the internal passageways 183 connected to actuators 170, 172. The

valve 200 controls the flow from the internal supply gallery 196 to the actuators and drain as will be described below.

**[0062]** The fluid flow controlled by the control valve 200 is obtained from the pressure conduit 78 and supplied through an accumulator 220 located in the bore 194 of control housing 18 adjacent to the control valve 200. The accumulator, shown in Figure 14, includes a piston 222 slideable within a cylinder 224 and biased by a spring 226 to a minimum volume. The piston 222 carries a stop 228 that limits displacement of the piston 222 within the cylinder 224. The stop 228 in combination with the spring 226 effectively establishes a maximum stored pressure for the accumulator 220. The supply gallery 195 extends through a branch conduit 227 to the interior of cylinder 224 and is connected with the pressure conduit 78 through a check valve 230 located in an internal bore 232 in the housing 14. The check valve 230 ensures that the pressure fluid in the accumulator 220 is maintained as the pressure supplied to conduit 78 fluctuates and that control fluid is available to the valve 200. The supply gallery 195 is also connected to the pressure compensated flow control valves 168 to ensure a constant flow of fluid to the bearings 160, 162.

**[0063]** To provide control signals to the valve 200, a block 202 is secured to the swashplate 142 within the horseshoe extension 186 and presents a planar surface 204. A position sensor 206 engages the planar surface 204 eccentrically to the axis of rotation of the swashplate assembly 140 to provide a signal indicative of the disposition of the swashplate assembly 140. The position sensor 206 includes a pin 208 slideable within a sensing block 210 that extends downwardly from the control housing 18. The pin 208 is formed from a stainless steel so as to be non-magnetic and has a magnet 212 inserted at its inner end. The sensing block 210 accommodates a Hall effect sensor 214 in a vertical bore 215 where it is sealed to prevent migration of oil from the cavity 20 to the control housing 18. The sensor 214 provides a varying signal as the pin 208 moves axially within the block 210. The Hall effect sensor thus provides a position signal that varies as the swashplate is rotated by the actuators 170, 172.

**[0064]** The sensing block 210 also carries a further Hall effect sensor 216 located in a bore 217 extending through the block 210 to a nose 219 positioned adjacent to the toothed ring 60. The sensor 216 is sealed in the bore 217 and provides a fluctuating signal as the teeth 62 pass it.

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so that the frequency of the signal is an indication of rotational speed of the barrel 22. The control signals obtained from the Hall effect sensors 214 and 216 are supplied to a control circuit board 218 located within the control housing 18. Further input signals, such as a set signal from a manual control, a temperature signal indicating the temperature of fluid in the machine, and a pressure signal indicating the pressure of fluid in the pressure conduit 78, are obtained from transducers located in or adjacent to the conduits 78, 80. The input signals are also fed to the control circuit board 218 which implements a control algorithm using one or more of the set, pressure, temperature and flow signals fed to it. The output from the control circuit board 216 is provided to the control valve 200 which is operable to control the flow to or from the actuators 171, 172 in response to the control signal received.

[0065] The operation of the machine 10 will now be described. For the purpose of the description it will be assumed that the machine is functioning as a pump with the shaft 24 driven by a prime mover such as an electric motor or internal combustion engine. Initially, the bias of the springs has moved the swashplate 140 to a position of maximum stroke and fluid in the accumulator 220 has discharged through the flow control valves 168. Rotation of the shaft 24 and barrel 40 causes full stroke reciprocation of the pistons 58 as the slippers 92 move across the lapped plate 150 to discharge fluid into the pressure port 78. The fluid is delivered through the check valve 230 to the supply gallery 195 to provide fluid to the control valve 200 and charge the accumulator 220.

[0066] In its initial condition, the control is set to move, the swashplate assembly 140 to a neutral or no-flow position. Accordingly, as fluid is supplied to the control valve 200, it is directed to the actuator 170 to move the swashplate 140 to the neutral position. As the swashplate moves toward the neutral position, the pin 208 of position sensor 206 follows the movement and adjusts the position signal provided to the board 218. Upon attainment of the neutral position, the flow to the actuator 170 is terminated by the valve 200. In this position, the barrel 22 is rotating but the piston assembly 58 is not reciprocating within the barrel. The accumulator 220 is charged to maintain supply to the flow control valves 168 through the gallery 195, and to the control valve 200.

[0067] After initialization, the circuit board 218 receives a signal indicating a movement of the swashplate assembly 140 to a position in which fluid is supplied to the pressure port 78. The signal may be generated from the set signal, such as a manual operator, or from a pressure sensing signal and results in a control signal supplied to the valve 200. The valve 200 is moved to a position in which it supplies fluid to the actuator 170 and allows fluid from the actuator 172 to flow to a sump. The supply fluid to the actuator 170 causes the piston 176 to extend and bear against the pin 190. The internal pressure applied to the piston 176 causes rotation of the swashplate assembly 140 with the surface 146 sliding across the surface 158. Until such time as pressure is delivered to the pressure port 78, the pressurized fluid is supplied from the accumulator 220 through the control valve and into the interior of the actuator 170 to induce the rotation. As the swashplate assembly is rotated about its axis, the slippers 92 are retained against the lapped plate 150 and the stroke of the pistons 90 is increased. Fluid is thus drawn through the suction port 69 past the kidney port 82 and into the pistons as they move outwardly from the barrel. Continued rotation moves the pistons into alignment with the pressure port 78 and expels fluid from the cylinders as the pistons 90 move into barrel. The pressure supplied to the port 78 is also delivered to the internal supply galleries 195 to replenish the accumulator 220.

[0068] As the swashplate rotates, the pin 208 follows the movement of the planar surface 204 and provides a feedback signal indicative of the capacity of the barrel assembly 22. The signal from the toothed ring 60 also provides a feedback signal indicative of rotation so that the combination of the signal from the pin 208 and the signal from the ring 60 may be used to compute the flow rate from the pump. If the set signal is a flow control signal then the combination of the speed and position are used to offset the set signal and return the valve 200 to a neutral position once the required flow is attained. Similarly, if the set signal indicates a pressure signal, then the pressure in the port 78 is monitored and the valve returned to neutral upon the set pressure being obtained.

[0069] As the swashplate 142 is adjusted, the flow of fluid into the grooves 160, 162 on the rear face 146 of the swashplate is controlled by the flow of the control valves 168 so that a constant support for the swashplate is maintained. Similarly, the port plate 64 is maintained

against the end face by the action of the spring 68, 70 to maintain a fluid tight seal for the passage of fluid into and out of the barrel assembly 40.

[0070] Movement of the swashplate to a position in which pressurized fluid is delivered to the port 78 recharges the accumulator 220 as well as supplying flow to the actuators 170 and 172 and the grooves 160, 162. If the swashplate assembly 140 is returned to a neutral position, the pressurized fluid in the accumulator 220 is sufficient to provide the control function and maintain the balance of the swashplate 142.

[0071] During adjustment of the swashplate 142, the rolling action of the pins 190 across the end faces of the pistons 176 further minimizes the frictional forces applied to the swashplate 140 and thereby reduces the control forces that must be applied.

[0072] It will also be appreciated that by providing the ball joint 94 as part of the slipper, the forces imposed on the slipper are minimized and the angle of adjustment available increased to enhance the range of follow rates that are available.

[0073] All movement of the swashplate 140 is followed by the pin 208 and variations in the rotational speed are sensed by the pickup 216 to permit the control board 218 to provide adjustment of the control parameters. It will also be noted that the control function is located in the housing 18 separate from the rotating component so that the control board 218 and associated electric circuit is not subject to the hydraulic fluid that might adversely affect their operation.

[0074] The provision of the key 42 on the shaft 24 inhibits relative rotation between the shaft and barrel and thus reduces the oscillation and fretting that otherwise occurs with a typical splined connection. Any misalignment between the barrel and port plate 64 is accommodated by the spring biasing applied to the port plate 64 by the springs 68, 70 so that the keyed connection to the shaft is possible.

[0075] The accumulator provides a supply of pressure fluid to the control valve 200 to enhance the response to variations in the control signal when the pressure in the discharge system falls below the accumulator setting.

[0076] If the machine 10 is to be utilized as a motor, it will be appreciated that the pin 208 is operable to follow movement of the swashplate to either side of a neutral condition and therefore provide reversibility of the output shaft 24 that is used to drive a load. During such operation,

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the line 78 will be at a low pressure but the accumulator 220 supplies fluid to the control valve 200 to maintain control of the swashplate.

[0077] In the above embodiment, the port plate is biased against the end plate and floats relative to the barrel 40. An alternative embodiment is shown in Figures 21 to 26 in which like components are denoted with like reference numerals with a suffix 'a' added for clarity.

[0078] In the arrangement shown in Figures 21 to 26, the port plate 64a is arranged to float relative to the end plate 16a and for relative rotation to occur between the barrel 40a and the port plate 64a. The port plate 64a is biased into sealing engagement with the barrel 40a by springs 68a received in a counterbore 68a. In this way, minor misalignment between the barrel and end plate is accommodated. The counterbore 68a is sealed to the end plate 16a by sleeves 74a that accommodate axial movement and maintain a seal with O-rings 76a.

[0079] As can be seen from Figure 22, the port plate 64a has a pair of kidney shaped ports 300, 302. The port 300 extends through the plate 64a with a central web 304 recessed from the front face 306 of the plate 64a. The rear face 308 as shown in Figure 24, is undercut as indicated at 310 to provide a clearance between the plate 64a and the end wall 16a.

[0080] The port 302 extends partially through the plate 64a and is intersected by three pressure ports 312 that extend from the rear face 308. Each of the ports 312 is configured to receive a sleeve 74a which engages in complimentary recesses in the end face 16a to provide a sealed communication between the plate 64a and the end face 16a.

[0081] A restricted orifice 314 is formed at the inner end of the counterbore 68a so as to extend through to the front face 306. The orifice provides a restricted access to the chamber formed by the sleeve 74a within the counterbore 68a and is positioned between the kidney ports 300, 302. A V-shaped notch 316 is formed in the front face 306 and progressively increases in breadth and depth toward the leading edge of the kidney port 302.

[0082] In operation, the front face 306 of plate 64a is forced against the end face of the barrel 40a. The bores 50a are located at the same radius as the kidney ports 300, 302 and therefore pass successively over the port plate as the barrel 40 rotates. As the bores 50a traverse the port 300 fluid is induced into the cylinders. Similarly, as the bores 50a traverse the port 302, fluid is expelled from the cylinders and directed through the sleeves 74a to the pressure conduit 78a.

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During this rotation, the face 306 is maintained by the springs 68a against the barrel 40a to maintain an effective seal.

[0083] It will be noted that the adjacent ends of the ports 300, 302 are spaced apart by a distance greater than the diameter of the bores 50a. This is shown in Figure 26A where the disposition of the bores at a particular position of the barrel 40a is shown. The bore 50a shown in chain dot line is associated with a piston that has just passed bottom-dead center, ie. the maximum volume of the cylinder and is starting to move axially to expel fluid. However, the rate of movement of the piston is relatively small by virtue of the sinusoidal nature of the induced movement. In the position shown in Figure 26A, the cylinder has just passed the terminal portion of the inlet port 300 but the small land created between the end of the bore and the terminal edge of the port 302 is such that there is a small leakage from the piston into the low pressure port 300. It will also be observed from Figure 26A that the orifice 314 is positioned within the cylinder.

[0084] As the barrel continues to rotate as shown in Figure 26B, the bore is centered over the orifice 314 and the limited movement of the piston is accommodated by compression of the fluid and components within the chamber 68a. Again, because of the sinusoidal nature of the motion, the axial displacement is minimized during this portion of the rotation. Further rotation of the barrel 40a brings the bore 50a to a position shown in Figure 26B in which it overlaps the notch 316 and therefore fluid in the cylinder may be expelled into the high pressure kidney port 302. The tapered dimensions of the notch 316 allows the oil to progressively enter the port 302 to avoid an abrupt transition and thereby reduce potential noise. At this time the cylinder is still in communication with the bore 68a and high pressure fluid within that bore can be expelled through the orifice 314 and into the pressure port 302.

[0085] Continued rotation, as shown in Figure 26D moves the bore 50a so it begins to overlap the kidney part 302 and has unrestricted access to the pressure conduit 78a.

[0086] Similarly, as the bore 50a moves from the inlet port 300 to the pressure port 302, a circumferentially spaced bore indicated at 50a' on Figure 26A moves from the high pressure kidney port 302 to the suction port. As can be seen from Figure 26A, as the piston approaches top-dead center, the communication with the high pressure port is progressively reduced until, as

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